The influence of audience participatory noise on sound levels at live events.

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ABSTRACT

Although the importance of audience participation at events, in terms of verbal and non-verbal appreciation, is well recognised, the by-product, noise, primarily in the form of applause, cheering and whistling, has been subject to little study in terms of its impact on sound pressure levels. This paper presents findings from a preliminary study in this area, where the specific impact of audiences on overall sound levels is analysed using a dataset from real-world large-scale events. Results indicate that an audience is capable of significantly increasing an event's overall sound level, even though their active participation only constitutes a small proportion of the event duration. Since sound level limits do not distinguish between noise sources, this notable influence from the audience can prevent compliance with imposed limits and should be considered in future updates to sound level monitoring systems and standards/regulations.

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1. INTRODUCTION

Sound level monitoring and management at large-scale live events have become commonplace over the past few decades [1,2,3]. In practice, however, the focus primarily resides with the output of a sound system as this tends to be the most dominant source of sound exposure to audience members and staff at an event [4,5,6,7]. The contribution of an audience, though, cannot be overlooked in many cases, especially when considering popular music events.

This paper details a preliminary study into the impact of so-called “audience participatory noise” on the overall sound exposure at large-scale popular music live events. While the audience can be considered a constant source of noise due to background chatter between acts and songs, the focus of this work is on active audience participation in direct response to what is happening on stage. This could be in the form of cheering, yelling, whistling, and so on.

Such noise, while impossible to control by a sound engineer, must be still considered when monitoring decibels, with respect to the enforced sound level regulations. This research, therefore, primarily focuses on the impact an audience can have on sound levels in relation to imposed limits. A novel analysis technique is presented and applied to real-world data gathered at large-scale live events over the past decade. The analysis allows for the isolation of the active audience contribution to the sound exposure, providing a clear demonstration of how significant an influence the audience can be in certain scenarios.

The paper begins with a brief review of previous work and knowledge in this area in Section 2. This is followed by an explanation of the selected data analysis method in Section 3 with the results given in Section 4, including a focused discussion on the implications of these findings, leading to key conclusions and suggestions for further research in Section 5.

2. BACKGROUND

The academic study of audience noise, in terms of Sound Pressure Level (SPL), tends to focus on orchestral music regarding the raised noise floor created by audiences during a performance [8,9] However, the importance of audience participation, from which noise is a product or by-product, is well recognised. Live performances are social encounters where audiences interact with artists and with each other, in a series of “verbal and non-verbal signals that evolve in real-time, and that contribute to the participatory experience”, and form a “bridge between the individual reaction and the collective experience” [10]. These signals equate to the high levels of participatory noise generated by audiences during rock, pop and dance performances. The social conventions of different genres dictate differing responses, but an audience expresses appreciation for a good performance by the strength and nature of its applause [11]. The participatory noise can be present in many forms, often simultaneously. A thunder of applause often turns into synchronized clapping, and this synchronization can disappear and reappear several times during the applause. Applause can contain verbal content such as shouting, whistling and singing, as well as non-verbal noise.

Audience participatory noise at concerts, from an academic perspective, in terms of its impact on the overall noise level at rock and pop events, is well recognised, but has not, to the authors' knowledge, been subjected to a great deal of formal research. From the authors’ perspectives, however, it is a significant part of the sonic content and experience of a performance. The “roar of the crowd” is a positive attribute to any performance, however from a noise control perspective it can have a significant and sometimes negative impact.

With the increasing number of venues incorporating sound level limits at their events, any raising of the SPL within the venue will impact the regulatory noise limit. Noise limits are non-discriminatory, responding to the weighted SPL over a pre-determined period. The performance of the artist and the sound system they employ to distribute their music make up a significant percentage of this level. However, audience participatory noise can also contribute a significant and in some cases disproportionately negative effect on the overall SPL. A regularly cited case of this is The Beatles’ performance at Shea Stadium in 1965. As engineer Bill Hanley recalled “You couldn't hear yourself think, 46,000 teenage girls screaming at the top of their lungs” [12]. This situation has not changed. The participatory noise created by the audience at a Justin Bieber concert being, according to sound engineer Ken ‘Pooch” Van Druten, equally problematic [13].

The authors' combined and shared experiences reflect the ongoing problem of noise created by the audience. This problem can be exacerbated by the popularity of whistles. Engineer Nick Warren noted that when working for popular boy bands in the 1990s, the selling of whistles by the tour merchandisers rendered many concerts almost unbearable due to the noise the audience was making [14]. A similar situation was encountered in football in the 2009 Confederates Cup and 2010 World Cups with the vuvuzela supporter’s horn. Spanish football player Xabi Alonso commented, “We’re used to people shouting but not to this trumpet noise which doesn’t allow you to concentrate and is unbearable…” [15]. The SPL produced by audience participation, in this case, was extreme, however, audience noise can have a real and significant impact on SPL levels.

The effect of the audience on the overall SPL can impact in several ways. Much care is taken in venues to distribute the acoustic energy of the artist's performance onto just the audience area, using carefully planned and managed systems. Attention is given to avoid sound hitting areas where it is not needed, such as the ceiling of the venue, high walls etc. This has the effect of containing the sound and helping reduce the reverberation within the venue. Audience noise is under no such constraints and can in certain situations be exacerbated by certain venue characteristics producing a very high SPL at the sound level measurement point. It can be particularly problematical in reverberant spaces, especially spherical or domed structures, such as circus-style tents, leading to the audience noise having a disproportionate effect on the overall measurement level. This has been the experience of the authors on multiple occasions.

The SPL produced by the sound reinforcement system is, to a great extent, controlled by the sound engineer. The noise of the audience, however, has no single control, being a collective reaction. It is not practical to attenuate the audience to reduce its contribution to the overall SPL. It is, however, important to be able to discern that contribution within the measurement. Noise levels tend to be penal by nature and the concern is the recognition of the factors that are realistically controllable, and those that that are not. The authors are all aware of situations where performances have been compromised due to high levels of audience noise impacting the SPL they are required to use to convey the artist's performance yet remain under a specified limit. They are also aware that their practice has put them in potentially litigious situations for high SPL over which they have no practical control, the audience's participatory expression of appreciation. This paper will examine ways that this issue can be explored, and the audience's participatory content can be explored and understood in relation to the noise produced as part of the artists' performance.

3. METHOD

The dataset used for this study was drawn from data collected by this paper’s first author at large-scale live events between 2015 and 2019. Eighteen events within the available dataset were singled out as the author noted the strong influence of the audience at these particular events, which took place either in Belgium or The Netherlands. All the data was collected using a calibrated Class 1 sound level meter, though a single-channel measurement at the front-of-house mix position (FOH), where the real-time sound level data was always visible to the sound engineer. The data was logged as $L_{eq,1sec}$ in A and C weightings and 1/3 octave bands.

The principal challenge for this analysis was to isolate data points consisting of sound energy predominantly originating with the audience rather than the sound system. Following on from the work in [5], this study adopted the general assumption that such a distinguishment can be made through an inspection of the C-weighted data, as audience noise is unlikely to contain any significant low-frequency energy.

While this study could have in theory implemented an inversion of the live dynamic range algorithm used in [5], which performs a similar analysis to remove non-musical data from the analysis process, a slightly simpler method was chosen due to the preliminary nature of this study, where it was necessary to pinpoint clear indicators of audience participatory noise.

An initial examination of the raw sound level data indicated that active audience participatory noise was most strongly concentrated in three 1/3 octave bands: 1 kHz, 1.25 kHz and 1.6 kHz. Regarding the musical content, the most consistent indicator of the presence of music was the 63 Hz 1/3 octave band. The principle for this simplified analysis was that if an increase in level is observed over the three identified audience noise bands and a corresponding decrease in the low-frequency musical band, then a data point can be considered to consist primarily of audience contributions to the logged sound level. Alternatively, a straightforward comparison between the A- and C-weighted sound levels could also potentially reveal the audience noise-influenced data points.

After carrying out a series of exploratory data analyses using the two above-mentioned techniques, it was determined that this preliminary study can use the simple difference between A- and C-weighted data. If $L_{Ceq,1sec} - L_{Aeq,1sec}$ is negative, it is assumed the audience is the dominant contributor to the logged sound levels (Figure 1). The authors expect, however, that a more robust data analysis method will eventually be required as this strand of research progresses beyond what is detailed in this paper.

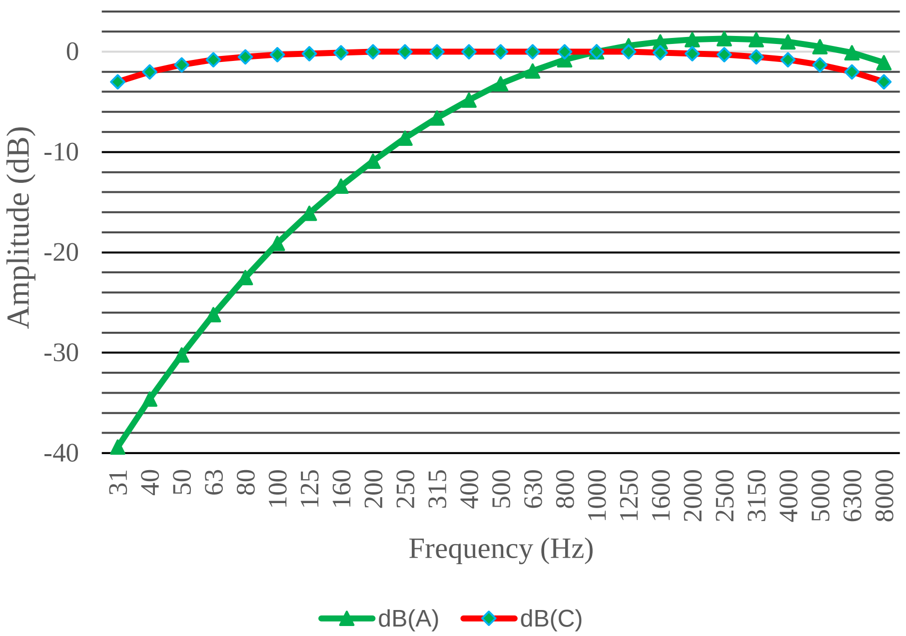

Figure 1: Relationship between A- and C-weighting curves [16]

The above-mentioned data analysis technique allows for the isolation of the audience participatory noise from the logged L_{eq} data. This permits clear analysis of the sound exposure due to the program material and the audience participation in isolation from one another. Assuming that the overall L_{eq} is reached through a combination of the program material (coming from the sound system) and audience noise, Equation 1 can be rearranged to solve for the audience influence (Equation 2).

$$L_{eq,total} = 10\log_{10}\left(\left(\frac{T-T_{aud}}{T}\right)10^{\frac{L_{eq,prog}}{10}} + \left(\frac{T_{aud}}{T}\right)10^{\frac{L_{eq,aud}}{10}}\right) \quad (1)$$

$$L_{eq,aud} = 10\log_{10}\left(\left(\frac{T}{T_{aud}}\right)10^{\frac{L_{eq,total}}{10}} + \left(1-\frac{T}{T_{aud}}\right)10^{\frac{L_{eq,prog}}{10}}\right) \quad (2)$$

where the audience noise continuous equivalent sound pressure level, $L_{eq,aud}$, is calculated based on the overall sound level, $L_{eq,total}$, and the program material dominated sound level, $L_{eq,prog}$. Knowledge of the duration of the event, T, as well as the duration of the audience-dominated sections within the logged data, T_{aud}, is required.

4. RESULTS AND DISCUSSION

Of the 18 events analysed within the available dataset for this study, the 11 events in Belgium had sound level limits by law [17] in place of 102 dB $L_{Aeq,15min}$ and 100 dB $L_{Aeq,60min}$. The remaining seven events took place in The Netherlands which has a covenant (not a law) in place specifying a sound level limit of 103 dB $L_{Aeq,15min}$. The results of the sound level data analysis are shown in Table 1.

Table 1: Complete results of the sound level data analysis (NL = The Netherlands, B = Belgium)

Year	Country	City	Act No.	T (mins)	T_{aud} (mins)	T_{aud}/T (%)	$L_{Aeq,tot}$ (dB)	$L_{Aeq,aud}$ (dB)	$L_{Aeq,aud}$ max (dB)	$L_{Aeq,prog}$ (dB)	ΔL_{Aeq} (dB)
2015	NL	Rotterdam	1	99	3.7	3.7	96.4	100.2	106.9	96.1	-0.3
2015	NL	Rotterdam	1	99	7.3	7.3	98.0	102.3	110.3	97.4	-0.6
2015	B	Brussels	1	100	4.0	4.0	96.5	100.5	108.7	96.2	-0.3
2015	B	Brussels	1	88	4.2	4.7	97.0	101.6	107.4	96.5	-0.5
2015	B	Brussels	1	102	5.4	5.4	96.9	101.8	109.8	96.4	-0.5
2015	B	Brussels	1	100	3.9	3.9	96.6	101.3	108.4	96.2	-0.4
2015	B	Brussels	1	100	5.0	5.0	96.9	102.1	110.1	96.4	-0.5
2016	B	Antwerp	2	124	9.0	7.3	100.3	106.1	113.2	99.1	-1.2
2016	B	Antwerp	2	130	10.7	8.2	99.6	105.5	112.1	98.3	-1.3
2016	NL	Arnhem	2	124	5.7	4.6	99.7	106.5	114.1	98.8	-0.9
2016	NL	Arnhem	2	122	6.8	5.6	99.8	106.1	113.5	98.9	-0.9
2018	B	Antwerp	3	91	2.8	3.0	99.0	104.8	112.5	98.6	-0.4
2018	NL	Amsterdam	4	116	5.4	4.6	100.0	102.8	108.0	99.8	-0.2
2018	B	Brussels	4	107	5.1	4.8	98.7	102.3	108.9	98.4	-0.3
2018	B	Antwerp	5	119	4.2	3.5	100.2	104.2	108.8	99.3	-0.9
2019	B	Brussels	6	136	10.0	7.4	97.0	101.3	110.8	96.4	-0.6
2019	NL	Amsterdam	7	101	6.8	6.7	101.0	106.2	112.3	100.2	-0.8
2019	NL	Amsterdam	6	82	7.3	8.9	97.3	101.8	109.1	96.5	-0.8

In Table 1, ΔLAeq represents the difference between the $L_{Aeq,tot}$ and $L_{Aeq,aud}$. The time frames for the various L_{Aeq} data displayed in Table 1 are as follows:

- $L_{Aeq,tot}$ (mean L_{Aeq} over the entire event): T (in minutes)
- $L_{Aeq,aud}$ (mean L_{Aeq} of the audience participatory noise): T_{aud} (in minutes)
- $L_{Aeq,prog}$ (mean L_{Aeq} of the program material): $T - T_{aud}$ (in minutes)
- $L_{Aeq,aud\ max}$ (maximum participatory noise level): 1 second

On average, active audience participatory noise was observed to increase an event's L_{eq} by 0.6 dBA (with a standard deviation of 0.3 dBA). The maximum audience influence on the L_{eq} was a 1.1 dBA increase. The minimum influence, 0.2 dBA, occurred at a children's musical event, where most attendees were under the age of 12 years old.

The highest recorded audience noise level (over a 1 second period) was $L_{Aeq,1sec}$ = 114.1 dBA, with an average maximum over all analysed events of $L_{Aeq,1sec}$ = 110.3 dBA (2.1 dBA standard deviation). This is in line with typical program material peaks that have been revealed in previous research [18,19]. Considering that the average percentage of an event occupied by audience participatory noise was 5.5% (1.7% standard deviation), the observation of an approximately 1 dB L_{Aeq} increase in level at most events (spanning at least 1.5 hours) due to the audience is significant. Taking the maximum audience levels into account, audience participatory noise has the potential to be a significant factor in audience sound exposure at popular music live events.

As an example, an extract of the sound spectrum over time from one of the analysed events (from Act 2 as indicated in Table 1) is presented in Figure 2. In this figure, data is presented in one-second segments, including $L_{Aeq,1sec}$, $L_{Ceq,1sec}$ and 1/3 octave band data.

Time	dB(A)	dB(C)	C-A	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz	2.5 kHz	3.15 kHz	4 kHz	5 kHz	6.3 kHz
20:31:00	97,2	109,3	12,1	71	68	68	84	80	77	85	76	78	81	76	81	91	84	90	89	80	81	84	81	79	75	73
20:31:01	95,4	118,0	22,6	84	81	82	80	76	75	87	80	86	80	75	81	82	81	88	84	79	79	80	78	78	70	68
20:31:02	96,7	117,5	20,8	82	86	72	79	78	74	81	81	88	81	77	79	88	83	87	87	86	82	84	80	76	73	70
20:31:03	99,6	118,4	18,8	75	89	80	76	74	72	78	78	90	86	80	80	92	90	93	88	85	84	86	84	81	79	76
20:31:04	97,5	113,3	15,8	68	84	81	74	78	70	76	79	89	87	80	81	89	85	91	87	83	82	83	79	77	72	72
20:31:05	98,1	108,4	10,3	56	68	73	79	86	81	73	79	84	84	79	83	88	88	91	91	83	85	86	80	79	75	72
20:31:06	98,5	113,9	15,4	72	82	81	78	86	82	72	78	88	85	76	78	89	89	90	90	83	83	88	81	77	74	71
20:31:07	95,9	109,6	13,7	59	68	80	84	78	71	75	77	77	79	79	80	81	82	89	87	87	83	87	83	80	72	69
20:31:08	94,2	114,9	20,7	77	79	80	79	75	74	74	78	78	75	76	80	82	82	85	83	82	84	85	84	79	70	66
20:31:09	95,2	118,3	23,1	86	81	76	76	75	74	75	81	84	76	78	78	84	84	88	86	81	81	80	78	75	69	66
20:31:10	96,0	109,0	13,0	72	69	68	84	79	74	80	82	80	83	77	78	85	85	89	87	83	84	84	82	79	73	71
20:31:11	96,2	112,5	16,3	73	77	76	86	82	85	82	82	79	79	81	76	85	83	88	88	83	83	82	79	77	71	69
20:31:12	96,7	110,7	14,0	70	74	69	78	88	84	81	80	77	75	79	75	80	84	90	89	85	84	80	81	78	74	73
20:31:13	96,1	111,4	15,3	73	75	73	81	88	83	80	74	77	80	76	80	84	85	90	88	84	83	79	76	75	69	68
20:31:14	98,1	105,0	6,9	60	63	65	74	77	82	82	79	85	83	84	85	89	88	92	89	86	85	82	80	78	74	74
20:31:15	100,3	110,4	10,1	59	62	78	81	80	90	84	75	88	82	78	85	87	87	97	91	84	82	80	79	79	73	72
20:31:16	97,8	115,8	18,0	77	84	80	79	79	85	89	75	86	81	75	80	87	87	92	89	81	79	80	80	81	75	76
20:31:17	96,9	119,2	22,3	86	83	70	74	73	77	74	80	83	80	78	78	88	89	90	86	81	81	82	80	77	71	68
20:31:18	101,5	110,1	8,6	73	78	76	82	79	73	73	82	81	77	80	78	89	91	97	96	90	89	86	84	82	76	72
20:31:19	108,5	112,5	4,0	64	64	66	87	86	68	69	81	79	77	80	79	88	97	105	103	98	96	93	88	86	80	73
20:31:20	109,2	113,0	3,8	74	75	74	84	79	69	70	79	75	74	75	76	87	98	105	104	98	99	94	89	88	81	74
20:31:21	108,5	108,9	0,4	68	64	64	71	65	62	61	71	66	69	70	76	87	98	105	103	97	98	92	88	86	78	70
20:31:22	106,2	106,1	-0,1	55	51	54	66	62	49	50	62	60	64	69	75	88	95	103	101	95	95	91	86	84	77	69
20:31:23	103,7	103,4	-0,3	46	43	44	56	50	43	48	55	57	63	70	74	88	93	99	98	93	93	89	84	82	74	66
20:31:24	102,4	102,3	-0,1	35	33	33	45	41	44	50	52	58	65	72	74	90	92	98	97	92	90	87	82	79	72	64
20:31:25	100,3	100,0	-0,3	28	29	31	36	37	43	50	56	58	65	69	74	83	89	96	96	89	88	84	80	77	70	63
20:31:26	98,3	98,1	-0,2	25	30	33	38	39	43	49	54	58	63	68	73	81	89	95	93	86	85	82	80	75	67	60
20:31:27	95,2	94,9	-0,3	27	28	29	36	37	43	48	52	59	66	68	71	78	84	91	90	84	82	80	79	71	64	63
20:31:28	92,8	92,7	-0,1	25	30	33	38	39	43	49	53	59	65	69	70	76	82	89	88	82	80	77	75	69	65	59
20:31:29	90,7	90,6	-0,1	27	30	32	37	38	43	49	54	60	66	67	74	75	79	86	84	82	79	76	74	69	62	56
20:31:30	88,6	88,7	0,1	21	25	31	34	37	44	49	53	60	65	67	70	75	79	84	82	78	79	75	70	67	61	55
20:31:31	92,7	113,9	21,2	68	82	84	77	75	73	72	75	76	80	77	80	83	83	84	81	77	76	73	68	66	60	54
20:31:32	95,4	115,7	20,3	70	85	86	81	77	76	76	77	76	76	76	79	84	85	84	84	85	85	85	81	81	74	74
20:31:33	95,7	103,0	7,3	58	69	74	68	68	62	61	63	71	67	72	74	83	87	89	88	87	85	85	82	81	77	75
20:31:34	97,2	115,2	18,0	70	83	86	80	76	74	74	77	77	79	77	79	85	87	90	89	87	86	85	81	80	75	74
20:31:35	93,5	102,7	9,2	59	69	74	71	70	66	64	66	69	66	71	72	79	82	87	87	81	87	81	74	73	68	63
20:31:36	95,0	111,9	16,9	52	69	75	72	73	63	66	70	75	77	75	77	84	84	85	84	85	87	85	82	82	76	73
20:31:37	95,6	116,4	20,8	72	86	88	82	78	77	76	78	78	80	78	80	85	84	84	84	84	85	85	81	81	76	74
20:31:38	92,6	104,1	11,5	61	71	77	70	71	66	63	66	70	68	70	73	83	83	82	82	83	84	85	80	80	75	73
20:31:39	93,4	116,4	23,0	69	83	86	81	77	74	73	75	76	81	78	80	84	80	80	79	79	78	78	73	71	66	61
20:31:40	94,0	112,2	18,2	70	84	84	78	75	76	74	76	75	74	75	76	83	84	84	82	84	85	85	80	80	75	73
20:31:41	93,5	101,5	8,0	57	69	73	68	68	62	60	62	70	68	71	72	83	84	83	82	84	85	86	81	80	76	74
20:31:42	88,9	108,9	20,0	57	68	83	71	65	84	73	77	77	74	72	74	74	75	72	71	71	71	69	64	61	56	49
20:31:43	87,6	112,9	25,3	70	66	80	71	79	80	70	72	73	75	72	76	79	71	69	69	69	65	64	62	59	53	47
20:31:44	87,6	110,3	22,7	65	69	72	72	74	72	64	65	76	78	76	80	80	72	72	75	70	69	65	63	60	53	46
20:31:45	88,3	115,4	27,1	83	79	67	81	76	76	69	69	73	72	71	69	70	76	78	75	71	69	66	65	61	54	45
20:31:46	83,5	100,8	17,3	67	65	57	66	63	64	55	68	72	72	70	67	69	75	78	74	69	72	65	63	62	53	45
20:31:47	88,3	108,0	19,7	60	66	81	70	64	83	72	76	76	74	73	72	71	72	78	73	69	71	63	62	59	52	45

Figure 2: Example of spectra with yelling (seen between approximately 800 – 1600 Hz) just after a song at one of the events analysed for this study

Cells highlighted in yellow (column C-A) in Figure 2 indicate one-second segments where $L_{Aeq,1sec}$ is greater than $L_{Ceq,1sec}$, which are therefore considered to be data points representing active audience participation. In this case, the audience level is approximately 10 dBA above the typical observed program material level. Depending on the sound level monitoring software utilised at the event, this could result in a sound level limit violation warning, causing an inexperienced sound engineer to unnecessarily decrease the output of the sound system.

It must be noted that the typical sound level monitoring location at FOH is in the middle of the audience area and generally near many audience members. Contrast this to the relatively greater distance between the measurement microphone and the sound system and it becomes clear that, while the audience participatory noise is certainly high in level, their actual contribution in real terms may be overestimated due to the physical layout of the measurement and monitoring system. A potential solution to this could be to take a secondary measurement in another area of a venue, which is further away from the audience, thus giving a more balanced representation of both program material and audience participatory noise. Of course, this would require careful considerations regarding how the on-site sound level limit applies to this more remote location (which would likely be outside of the audience area itself). This area requires further research, including how to best track the audience's sound exposure to their self-generated noise and how this relates to whatever measurement and monitoring practices are in place.

Furthermore, in many cases, there will be post-festival events consisting of sing-alongs to popular music. Such events, mostly at night time regularly have a restricted sound level limit of around 95 dB $L_{Aeq,15min}$ in Belgium. As the audience participation contributions will largely remain the same as for a full-level popular music event, this could easily result in the audience increasing the overall L_{Aeq} by 10 dB due to the greater amount of (encouraged) audience participation and the lower limits in place. This should be cause for concern for key stakeholders, where there is no clear solution at present (barring the observation within the dataset from this study showing audience contributions to

L_{Aeq} to gradually decrease over the course of the event, presumably due to audience fatigue, therefore there may be a lesser audience contribution to L_{Aeq} for after events such as these).

It must be stressed that while within the study the audience noise has been isolated from the program material, legally, all sound energy must be considered regarding any imposed sound level limits. It may be useful to take a feed from the mixing desk to indicate within a sound level data log file when the recorded sound levels weren't due to the sound system output. This could be useful information (in terms of culpability) should an event encounter legal challenges due to sound exposure of audience members.

5. CONCLUSIONS

The present study provides an initial formal exploration of the impact of active audience participatory noise on sound levels at popular music live events. While the data analysis techniques applied here require further refinement to increase their robustness, the results give a clear indication that the audience is capable of significantly influencing the overall sound level at an event. Critically, this contribution cannot be ignored in terms of imposed sound level limits, although this source of sound exposure is almost entirely out of the hands of the sound engineer and other professionals responsible for monitoring and managing sound audience sound exposure.

In the analysed dataset, it was found that the audience-specific contributions to the sound levels occurred over roughly 5% of an event but showed peak levels greatly exceeding those of the actual program material emanating from the sound system. While it could be said that this is partially due to the measurement microphone's proximity to the audience, it could also be argued that audience members are entirely within their self-generated noise source and therefore could be experiencing even greater sound exposure than the measurement microphone indicates. This poses a problematic situation, as the recent WHO Global Standard on Safe Listening Venues and Events [4] specifies a sound level limit at the loudest representative location in a venue but gives no consideration as to whether that loudest location is due to the sound system or the audience (the assumption is that the standard's guidance is in relation to the sound system's output, as audience-generated noise isn't explicitly addressed).

There is a significant amount of further research required in this area. First, a more robust data analysis method must be developed. This could most likely adapt the live dynamic range algorithm presented in [5] to serve this purpose. Additionally, a wider dataset must be explored to better understand whether the significant audience impact on sound levels is limited to popular music events or whether this effect is observable at other varieties of events (not necessarily musical). With such knowledge and techniques in hand, the focus should be shifted to consider how such information can be embedded into sound level data log files and user interfaces, which critically may serve to absolve a sound engineer (or venue management) of culpability should audience sound exposure from a live event be legally challenged, but found to be due to audience-generated noise rather than program material from the sound system. Lastly, further research is required to better define measurement and monitoring protocols that are fit for purpose.

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